ARMY RESEARCH LABORATORY

Practices and Standards in the Construction of BRL-CAD Target Descriptions

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ARL-MR-103

September 1993

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NOTICES

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	September 1993	FINAL - AUG 92 TO MAY 93

4. TITLE AND SUBTITLE
Practices and Standards in the Construction of BRL-CAD Target Descriptions

5. FUNDING NUMBERS
PR: 1L162618AH80

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Research Laboratory
ATTN: AMSRL-SL-B
Aberdeen Proving Ground, MD 21005-5068

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Research Laboratory
ATTN: AMSRL-OP-CI-B (Tech Lib)
Aberdeen Proving Ground, MD 21005-5066

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
ARL-MR-103

11. SUPPLEMENTARY NOTES
This paper was presented at the BRL-CAD Users Conference 4-6 November 1992, held in Baltimore, MD.

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
BRL-CAD is a Government-developed geometric modeling system designed to support all aspects of the vulnerability/lethality (V/L) analysis field. In this report, we present a general overview type of approach to geometric modeling with BRL-CAD. The important link between the intended application/analysis and the specific requirements on the geometric model is discussed. An approach to effective BRL-CAD database management, based on the design of the database, is presented. We also suggest some basic naming conventions that have proven successful for armored systems. Finally, a general philosophy of geometric modeling and a modeling plan to accomplish any project are presented.

14. SUBJECT TERMS
Geometric modeling, BRL-CAD, solid modeling, target description, combinatorial solid geometry, vulnerability, models

15. NUMBER OF PAGES
52

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std Z39-18
298-102

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1. Introduction

The **B**allistic **V**ulnerability **L**ethality **D**ivision (**BVLD**),* formerly known as the Vulnerability Lethality Division of the **B**allistic **R**esearch **L**aboratory (**BRL**), has been involved in geometric modeling for four decades. From the very beginning, geometric modeling has been incessantly tied to the vulnerability/lethality (V/L) field. In fact, geometric modeling in the Army was specifically developed to support V/L assessments, and its subsequent evolution has continually been driven by the V/L requirements. With this direct connection to the V/L field, the development cycle of geometric modeling at the BVLD has certainly been atypical. Most other modern geometric modeling systems have their roots in the mechanical drafting field, and have subsequently been tied to the design/manufacturing environment. Thus, to understand the development of geometric modeling at the BVLD, one must first consider the history of the V/L analysis field.

2. Background

2.1 Vulnerability/Lethality Assessments

The vulnerability of a system is a measure of that system's susceptibility to damage when attacked by a particular threat mechanism. Lethality, on the other hand, considers the reciprocal, and estimates the damage a threat inflicts on a particular target. The earliest attempts at V/L assessments were concerned with tanks being attacked by direct fire weapons, and relied heavily on subjective judgement. The major concern was perforation of the armor; hence, the only geometric information needed was armor thickness and obliquity angle. The penetration capability of the attacking munition was matched against the armor. If perforation occurred, then estimates were made concerning damage and residual system combat capability. Methodology soon began to emerge, however, and by the late 1950s, computer codes existed to estimate damage sustained by armored vehicles attacked by direct fire munitions.

These early V/L analysis computer codes considered large numbers of shot locations on a target from several attack aspects. For each attack azimuth, shot locations were evaluated for a grid completely covering the target. The geometric information required was a formatted file containing a sequential listing of information about each component encountered for each grid cell (or shot location). The required information included the name of the component, line-of-sight thickness, entrance and exit obliquity angles, and the type of material. This information, known as *shotline* data, was manually derived. For each attack direction, a 4-inch grid was physically drawn over the appropriate engineering

* The BVLD is one division of the **S**urvivability **L**ethality **A**nalysis **D**irectorate (**SLAD**), an element of the **A**rmy **R**esearch **L**aboratory (**ARL**).

drawing. Then, on a cell-by-cell basis, the shotline data were estimated (see **Figure 1**) and written in the correct format to be evaluated by the V/L analysis computer code.

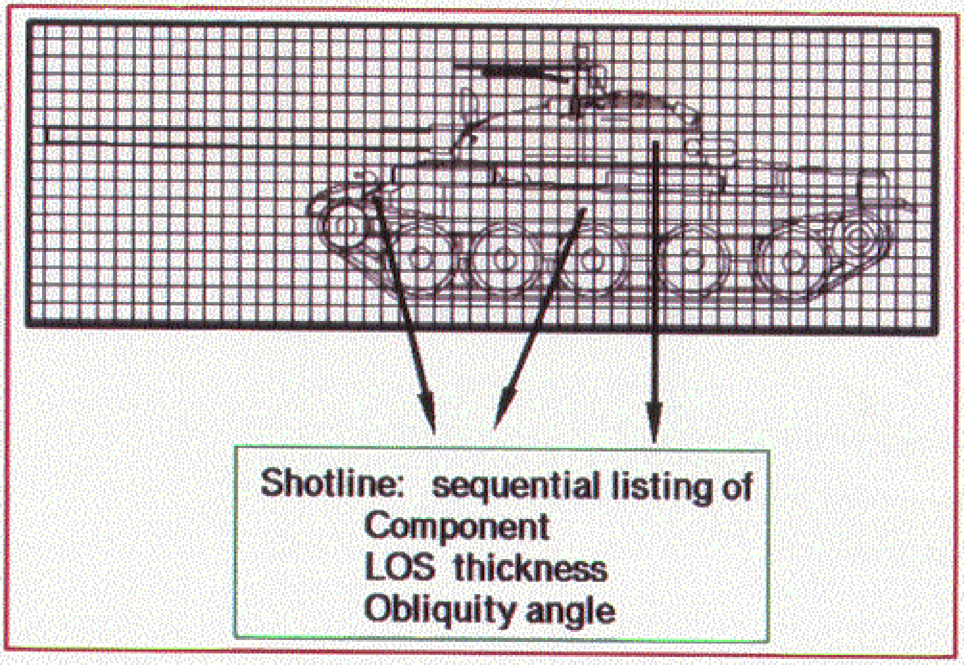


Figure 1. Manual Shotlines From Engineering Drawings.

This shotline generation procedure was unsatisfactory. The manual nature and subjectiveness made the whole process error-prone and time-consuming. In addition, only those attack views for which engineering drawings existed could be evaluated. The attempt to rectify these shortcomings led directly to the birth of 3-dimensional solid geometric modeling in the Army. The process certainly had to be computerized; hence, the solution to the shotline generation problem was twofold. First, a technique of representing the geometry of the target in the computer was required. Second, an algorithm which would allow the computer to interrogate the geometric representation stored in its memory and calculate the shotline data would complete the solution. In 1967, a contract with the **M**athematical **A**pplications **G**roup, **I**nc. (**MAGI**)[1] provided the solution. MAGI introduced the **C***ombinatorial* **S***olid* **G***eometry* (**CSG**) technique for representing geometry in a computer and the *ray-tracing* geometry interrogation scheme.

2.2 Combinatorial Solid Geometry

The CSG approach, still in use today, uses Boolean combinations of simple solid geometric shapes, or primitives, to model components at any level of detail. **Figure 2** is a rendering of the current set of primitives while **Figure 3** shows the results of several Boolean operations. The first geometric modeling system using the CSG technique required three separate files. The first file contained the

parameters of the individual primitives, defining the shape, size, location, and orientation of each. The second file defined the regions, which are the Boolean constructs combining the primitives from the first file. The third file identified the regions by labeling which component of the target each region represented. These CSG files constituted what has become known as a *target description*. The target description was required input to the ray-tracing code to produce the shotline information.

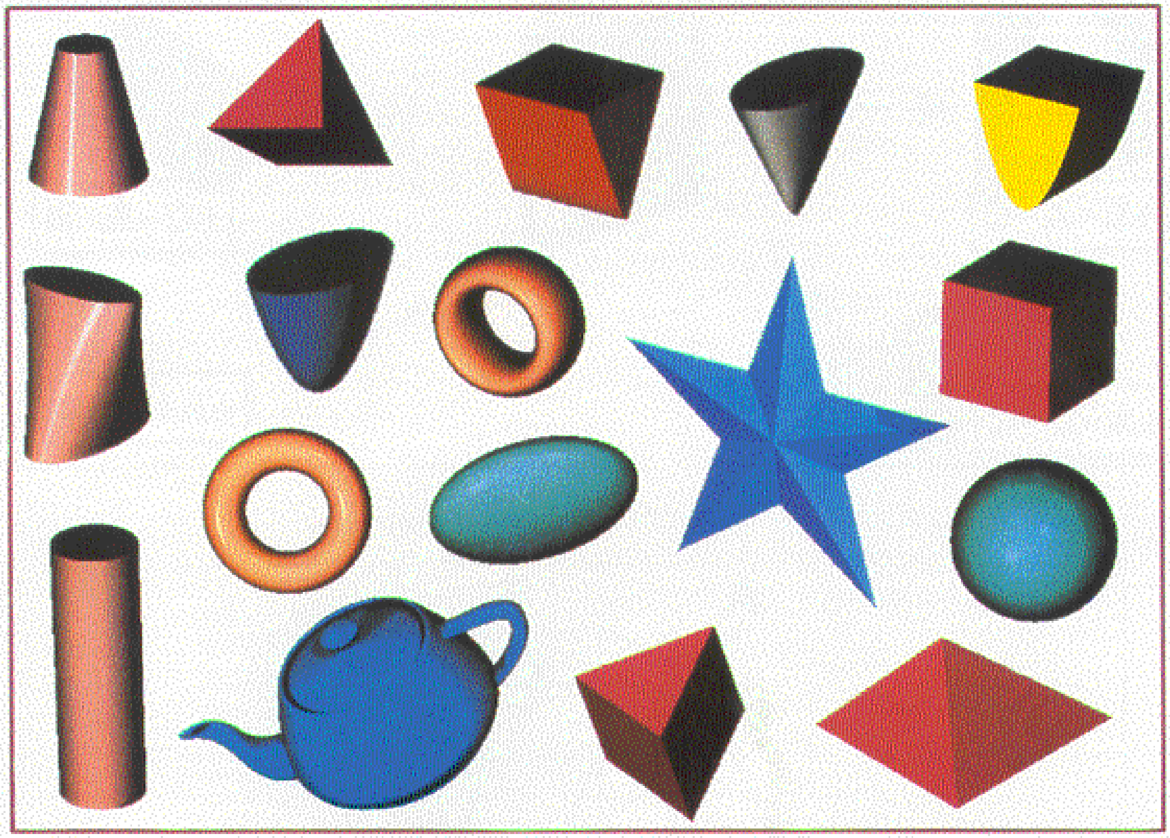


Figure 2. Sample CSG Primitives.

2.3 Ray-Tracing

The ray-tracing technique, as its name implies, mathematically intersects rays, or lines, with the CSG target description. Parallel rays are initiated from a "grid plane" oriented at the desired attack direction. These rays are intersected with the regions of the description. As the ray encounters a region, at the intersections with each of the defining primitives of that region, the 3-dimensional coordinate locations and surface normals are calculated. The primitive-ray intersections are then combined according to the Boolean formula for that region (see **Figure 4**) to produce the actual intersections for that region. These intersection coordinates are used to calculate thicknesses, which, along with surface normals and other information further identifying the region, constitute the shotline information.

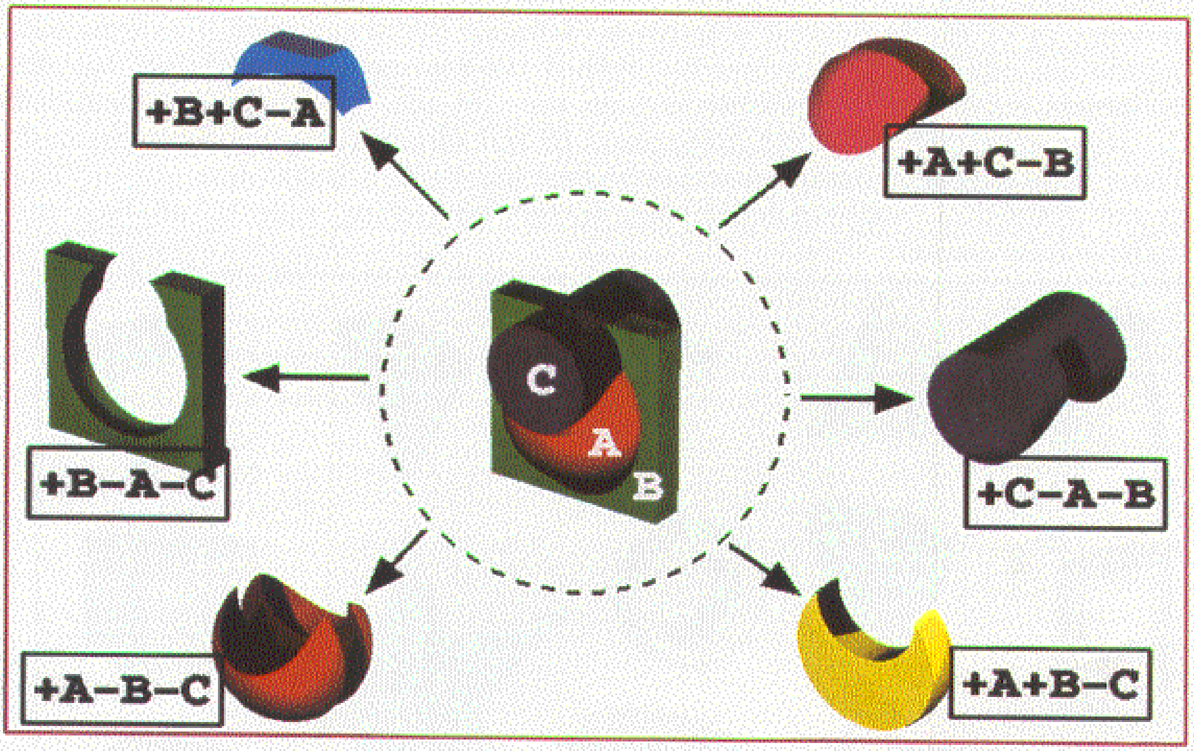


Figure 3. Examples of Boolean Operations.

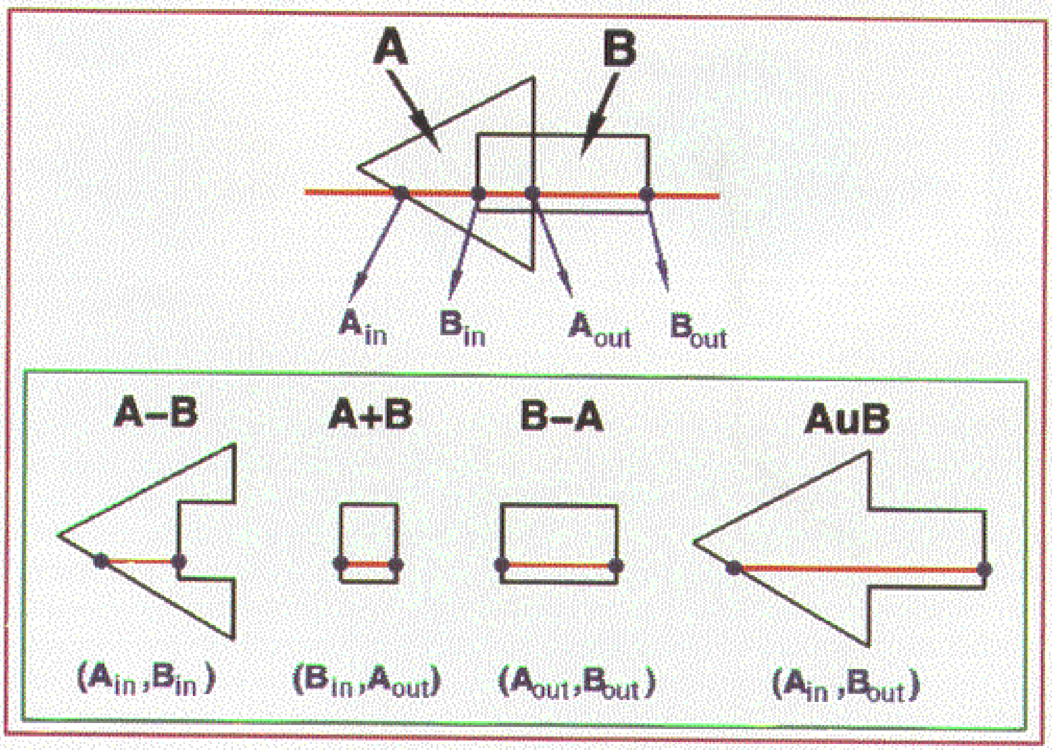


Figure 4. Ray-Tracing a Simple Region.

The ray-tracing code eliminated the shortcomings of the hand-generated shotline process and greatly increased the overall V/L capability. Parallel shotline information could now be quickly generated from any attack direction, including nonzero elevations. Furthermore, divergent rays could be used to simulate the *bursting* phenomenon. Ray-tracing continues, to this day, to be a flexible geometry interrogation tool and has been used to simulate many natural phenomena.

2.4 BRL-CAD

The development of the ray-tracing technique immediately turned the spotlight directly on the target description. In addition, new capabilities and more detailed analyses placed increased emphasis on the target descriptions. Soon the construction and validation of target descriptions became the most crucial and time-consuming element in the V/L process. The demand for highly detailed, accurate, and timely target descriptions quickly outdistanced the capability to produce them. The main reason was that the construction procedure itself remained a manual process, mired in a mainframe/batch computing environment. With the promise demonstrated by the emerging interactive computer graphics field and the move towards the open environment of the UNIX operating system, a long-term project was initiated in late 1970s to address this problem. The goal of this project was to create an interactive CSG geometric modeling system within the framework of a more flexible, portable computing environment.

In 1983, the first interactive CSG modeling system[2] was introduced. This system greatly reduced the time required to construct and validate CSG target descriptions. The computer hardware necessary to support this interactive modeling system was rather limited, and included a mini-computer driving a single display device. Soon, however, the graphics work-station entered the market, providing a tremendous boost to the target description preparation process. The work-station provided target describers with a powerful, dedicated computing platform, including excellent interactive graphics capability, all at a relatively low cost.

About the same time, the algorithms of the early ray-tracing codes were rewritten in the C programming language and put in a library. This library made the development of new ray-tracing-based applications codes much easier. The interactive modeling system and a large volume of associated software have been bundled into what is known as the *BRL-CAD* [3] package. This software has been distributed world-wide since 1987 and is continually being expanded and improved.

3. Analyses and Geometry Requirements

In the following sections we will examine the major types of analyses which utilize BRL-CAD geometry, presenting a brief synopsis of the capabilities, limitations, and requirements of each. Then we will discuss how these characteristics translate into demands on the geometric target description required to support

each level of analysis. The selection of analysis codes considered is not intended to be all inclusive, rather an examination of the major types of analyses most often encountered. The analysis codes will be considered in somewhat of a chronological order of development.

3.1 Nuclear Assessment

The **V**ehicle **C**ode **S**ystem (**VCS**)[4] is the nuclear vulnerability assessment code and is used to evaluate the shielding properties of a vehicle against initial nuclear radiation. The VCS code uses a Monte Carlo module, **M**ultigroup **O**ak **R**idge **S**tochastic **E**xperiment (**MORSE**)[5] code, to estimate radiation transport through the vehicle. The VCS code calculates estimates of the radiation dosage received by individual crew members, the only critical components of the target.

Target descriptions prepared for the VCS code have traditionally been the most limited and specialized. The VCS target description requirements[6] were first presented in detail in 1976. As significant advances have been made in computing power and memory, many of these restrictions no longer exist, but will be presented for completeness. The most restrictive condition was the limitation on the number of primitives allowed. In the late 1970s, nuclear target descriptions were limited to 600 primitives, preferably less than 300. This size restriction had several implications, the obvious being the amount of detail, which had to be used judiciously. Components with *like* attenuation characteristics had to be combined, while other components such as the hull, turret, suspension, and main armament had to be modeled in low detail. Larger components which would offer significant shielding, such as stowed ammo, also had to represented, but as an aggregate volume.

The size restrictions of the VCS code no longer exist; however, there are some requirements that still must be considered when preparing a VCS target description. An accurate description of the armor shell is required. Armor thickness is important, but unlike ballistic models, the obliquity angles are less critical. Still, since the target description may be used for other purposes, accurate obliquity angles should be modeled. The exterior shell should include areas where radiation particles may gain entrance. This means that detail and clearances are important in areas such as hatches, sighting devices, and air intake and exhaust grills and vents. All critical components that could be affected by radiation, including the crew, should be included. Likewise, all major internal components that provide shielding, must be represented. All internal air must be modeled as a regular component. Finally, the complete target must be enclosed in an external air region, sitting on a region representing the ground.

3.2 Compartment Level

The compartment-level vulnerability methodology was the first approach to V/L assessment and, as mentioned earlier, was the driving force behind the development of geometric modeling and ray-tracing. There were two early compartment-level V/L codes, one for kinetic energy warheads and one for chemical energy (shaped charge) warheads. In 1979, these codes were combined

into the VAMP[7] code. The compartment-level codes are the least sophisticated of the V/L codes. True to their name, these codes consider the target as a series of compartments contained within an armored shell. Penetration calculations are matched against the armor defeat criteria. Upon perforation, the residual energy (represented by a hole size) is used to predict damage from a *compartment kill curve*. The only internal components that are considered on an individual basis are those that would contribute to a catastrophic kill (K-kill) of the vehicle.

There are several important considerations when preparing a compartment-level target description. The armor shell must be described as accurately as possible since the thickness and obliquity angle are crucial in penetration calculations. Other exterior components that would affect penetration, such as the main gun, suspension components, and roadwheels, must be represented. **Figure 5** is a rendering of the exterior of a compartment-level description.

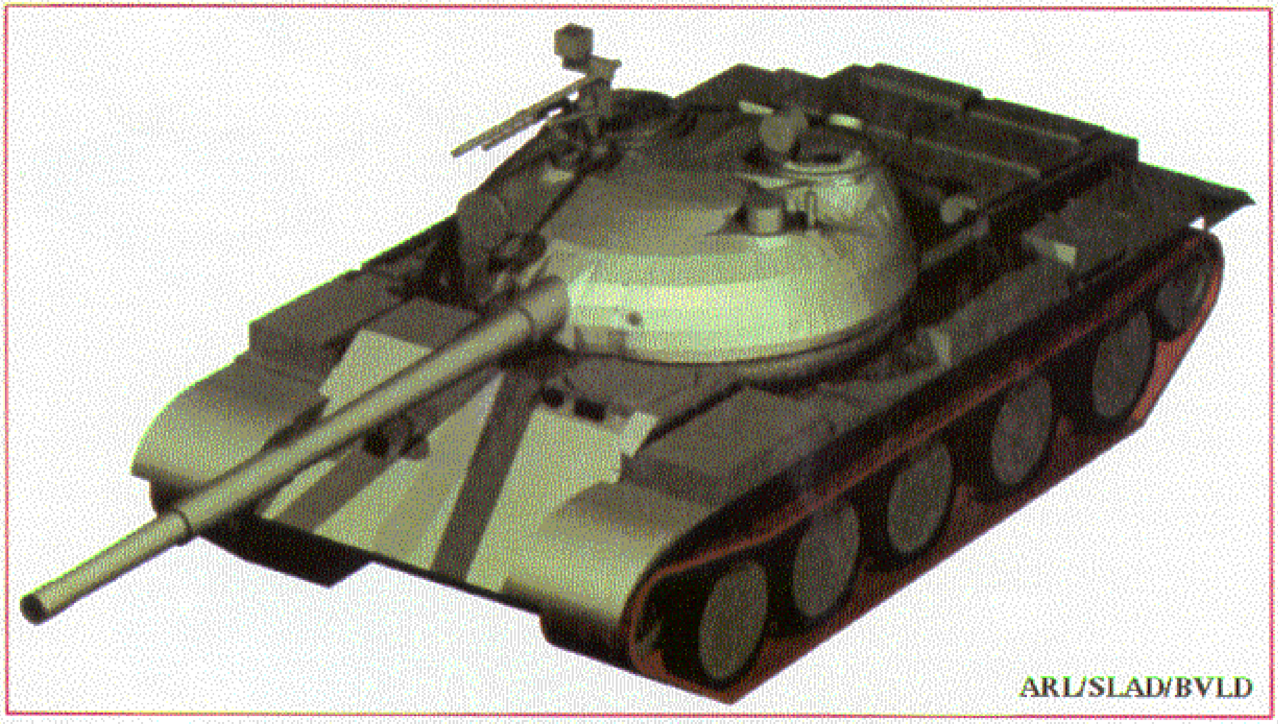


Figure 5. Exterior of a Compartment-Level Description.

The complete interior volume within the armor shell must be modeled and divided into compartments. The compartments of interest are the crew, engine, and ammo. Defining these compartments is accomplished by modeling air regions and assigning differentiating "air codes". There must not be any space between the inner surface of the armor and the air regions (compartments). There is interior space that must not be included as part of the crew, engine, or ammo compartments. These areas, such as between the hull belly and the floor and between the armor wall and an adjacent fuel tank, are modeled and identified as separate compartments. **Figure 6** shows these "compartment air regions" along with the enclosing armor shell. Any K-kill component, such as fuel tanks and

stowed ammo, must also be represented. In addition, large shielding components, such as engines and transmissions, are usually modeled at a low level of detail. Other interior components need not be modeled. **Figure 7** depicts the interior detail of a compartment-level target description.

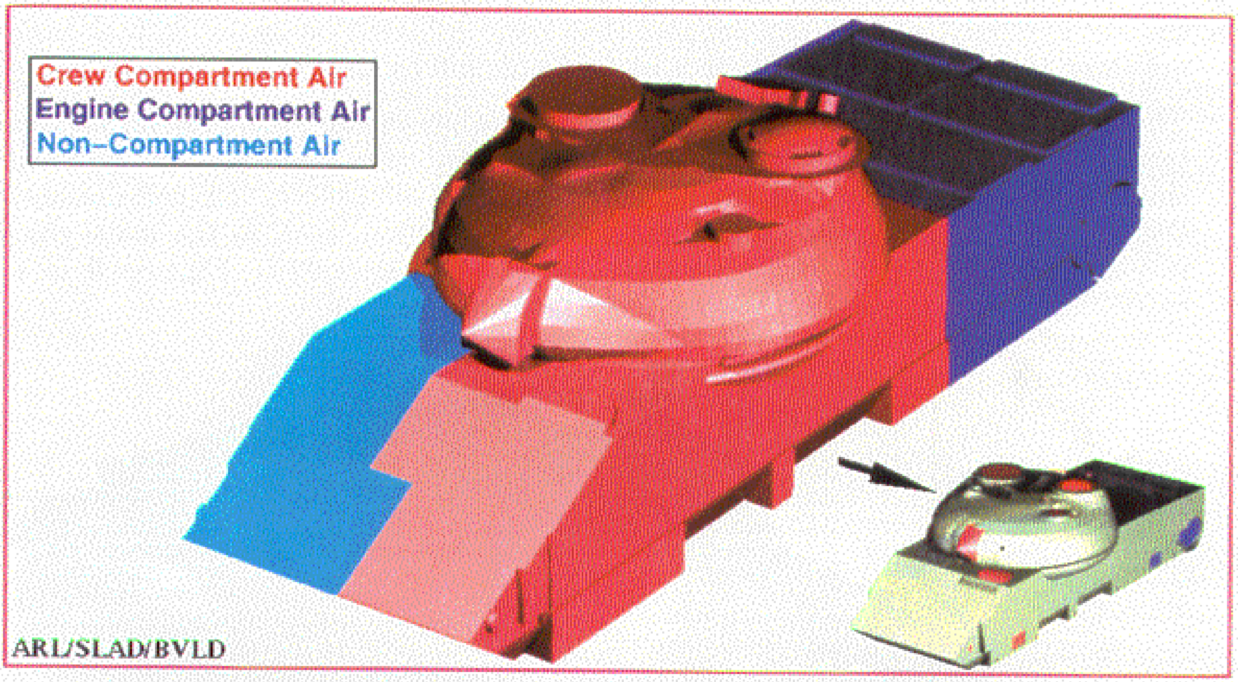


Figure 6. Air Regions Representing Internal Compartments.

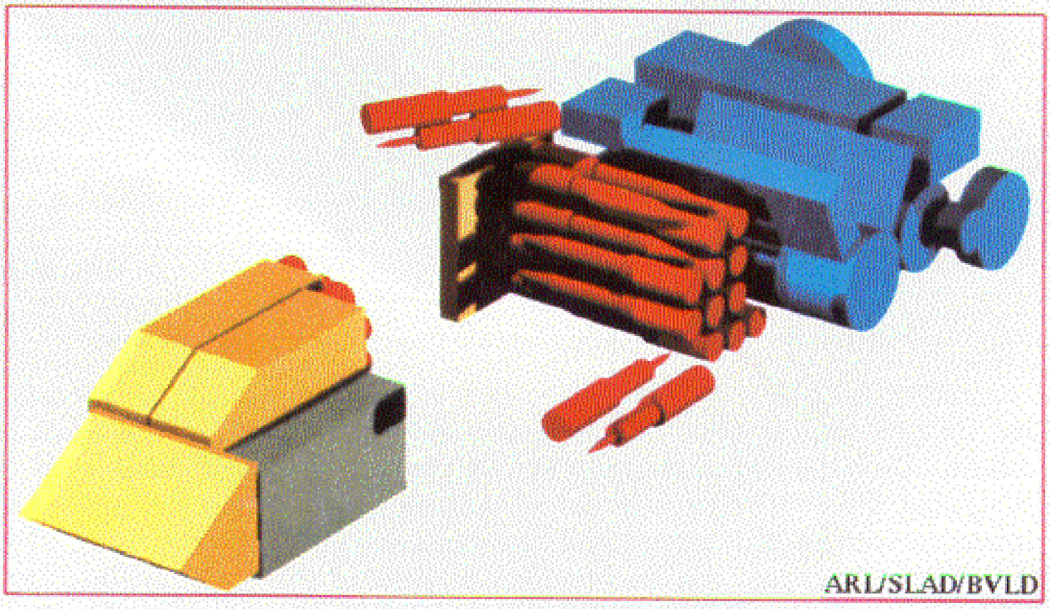


Figure 7. Interior of a Compartment-Level Description.

3.3 Component Level - Parallel Ray

The component-level vulnerability codes represent the next level of complexity in that the target is analyzed at the individual component level. The first such code was known as the VAREA[8] code and was used for lightly armored vehicles, trucks, etc. The COVART[9] family of codes performs similar tasks for aircraft. These codes compute the vulnerability estimates in terms of *vulnerable areas* for specific penetrators, usually fragments and small caliber direct fire weapons. This methodology requires component conditional kill probabilities given a hit for every critical component. The vulnerable area of the target from a specific view is the sum of all the individual grid-cell vulnerable areas. The grid-cell vulnerable areas are determined by calculating a cell probability of kill and multiplying it by the area of the cell. The view vulnerable area data are presented in a table for the various fragment mass and velocity combinations.

It is no surprise that the geometry requirements for the VAREA codes shifted emphasis to the individual component. The exterior shell must continue to be modeled as accurately as possible. Other exterior components must include any critical components plus any component that could contribute to a K-kill. Any exterior component should also be included if it provides any significant shielding or affects the penetration capability of the warhead. **Figure 8** shows the detail of the exterior of a component-level target description. All critical internal components must be modeled in enough detail to support a component kill analysis. The component conditional kill analysis uses presented areas of the component from several aspects, ratioing projected areas of *sensitive* regions with the total presented area. Thus, the presented area of the model of the component should accurately represent the real component. Any other noncritical internal component that provides effective ballistic shielding should also be included. At this level, components such as wiring harnesses and fuel and hydraulic lines are generally modeled. **Figure 9** is a rendering of the internal components of a component-level target description.

3.4 Component Level - Point Burst

The point burst assessment codes are simply an extension of the VAREA level codes, except the damage resulting from behind-armor debris (or spall) is explicitly estimated. Parallel shotlines are used to simulate the main penetrator while divergent shotlines (or spall rays) simulate the spall debris. The spall rays are initiated whenever a *burst point* is encountered along the path of a main penetrator. A burst point is defined whenever a main penetrator exits an armor component directly into an interior volume. The first point burst V/L code was the VAST[10] code, which evaluated kinetic energy and shaped charge warheads versus tanks. In 1988, a stochastic point burst V/L code called SQuASH[11] was introduced and represents a significant improvement in armored vehicle vulnerability modeling.

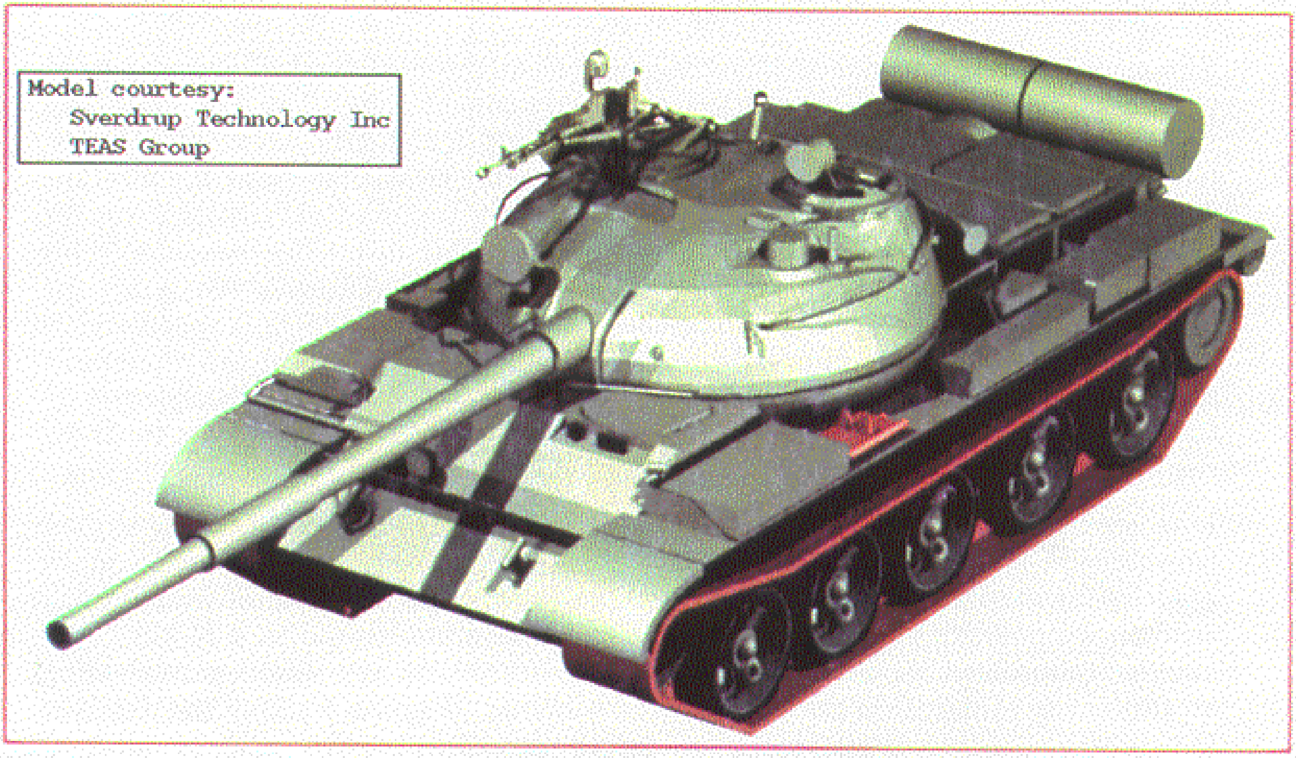


Figure 8. Exterior of a Component-Level Description.

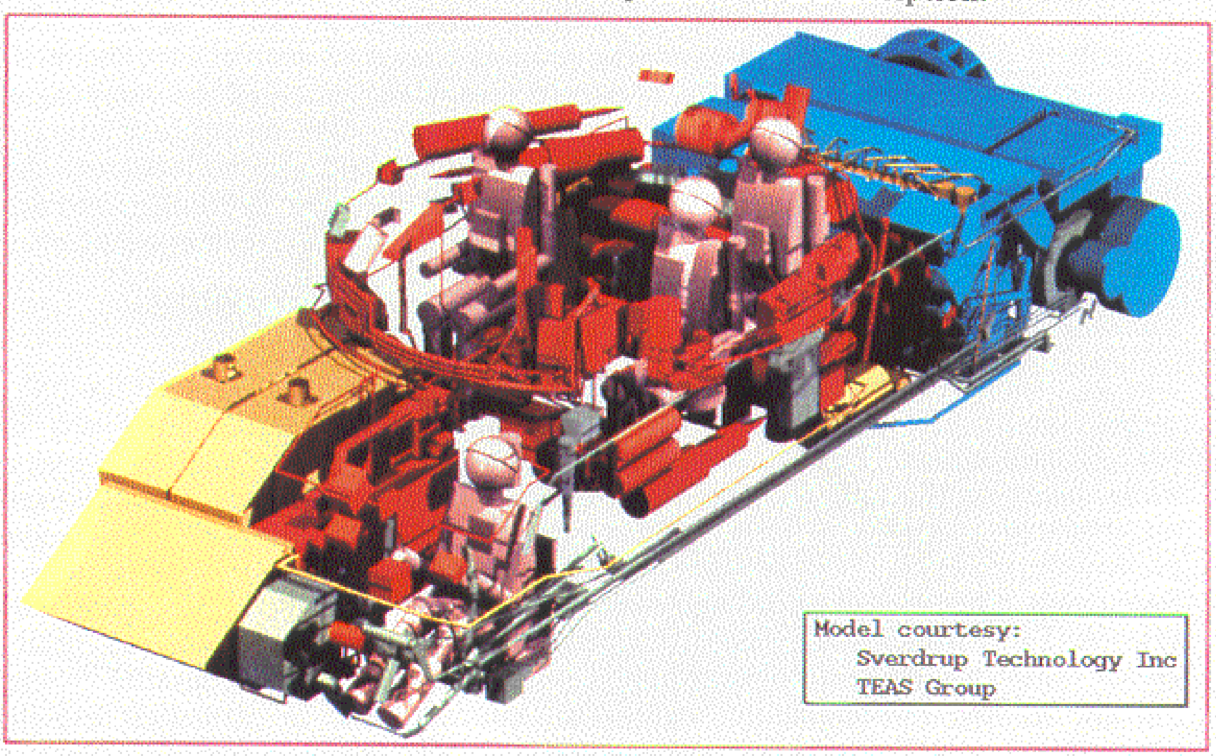


Figure 9. Interior of a Component-Level Description.

The geometry requirements necessary to support a point burst V/L analysis are nearly identical to the VAREA requirements as far as the components are concerned. The one major difference is the need to identify burst points. Recall, burst points are located on the inner surface of armor components that are adjacent to interior volume. Hence, to locate the burst points it is necessary to know when one has entered the interior. As in the compartment analyses, this is accomplished by representing all interior volume as air regions and then identifying those where spall rays should be initiated. Note that one should avoid any "undefined" volume between the exterior shell and the air regions, or the burst points could be missed. **Figures 10** through **13** are used to compare the detail of several subsystems of compartment-level and component-level target descriptions.

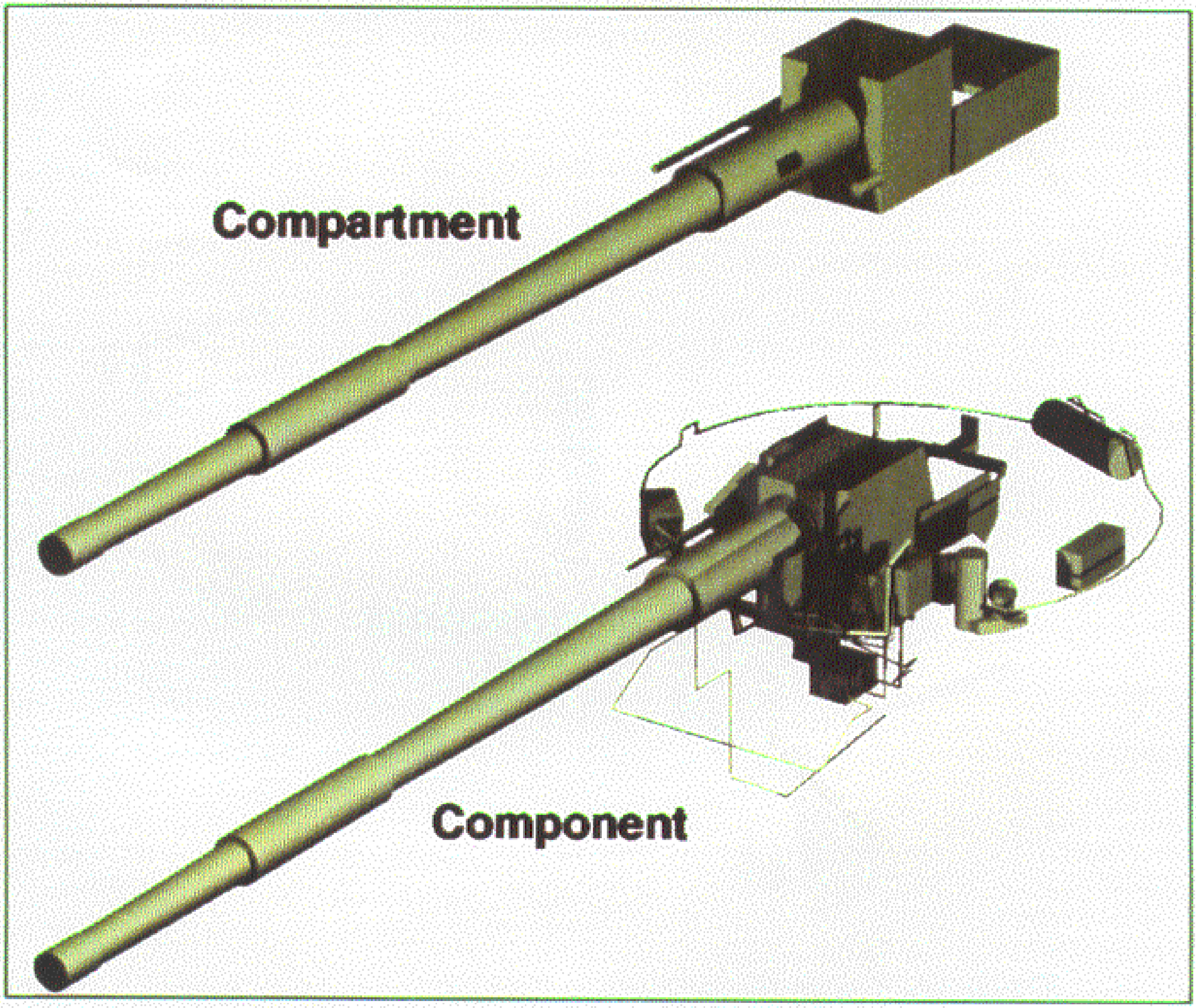


Figure 10. Compartment-Level and Component-Level Gun System.

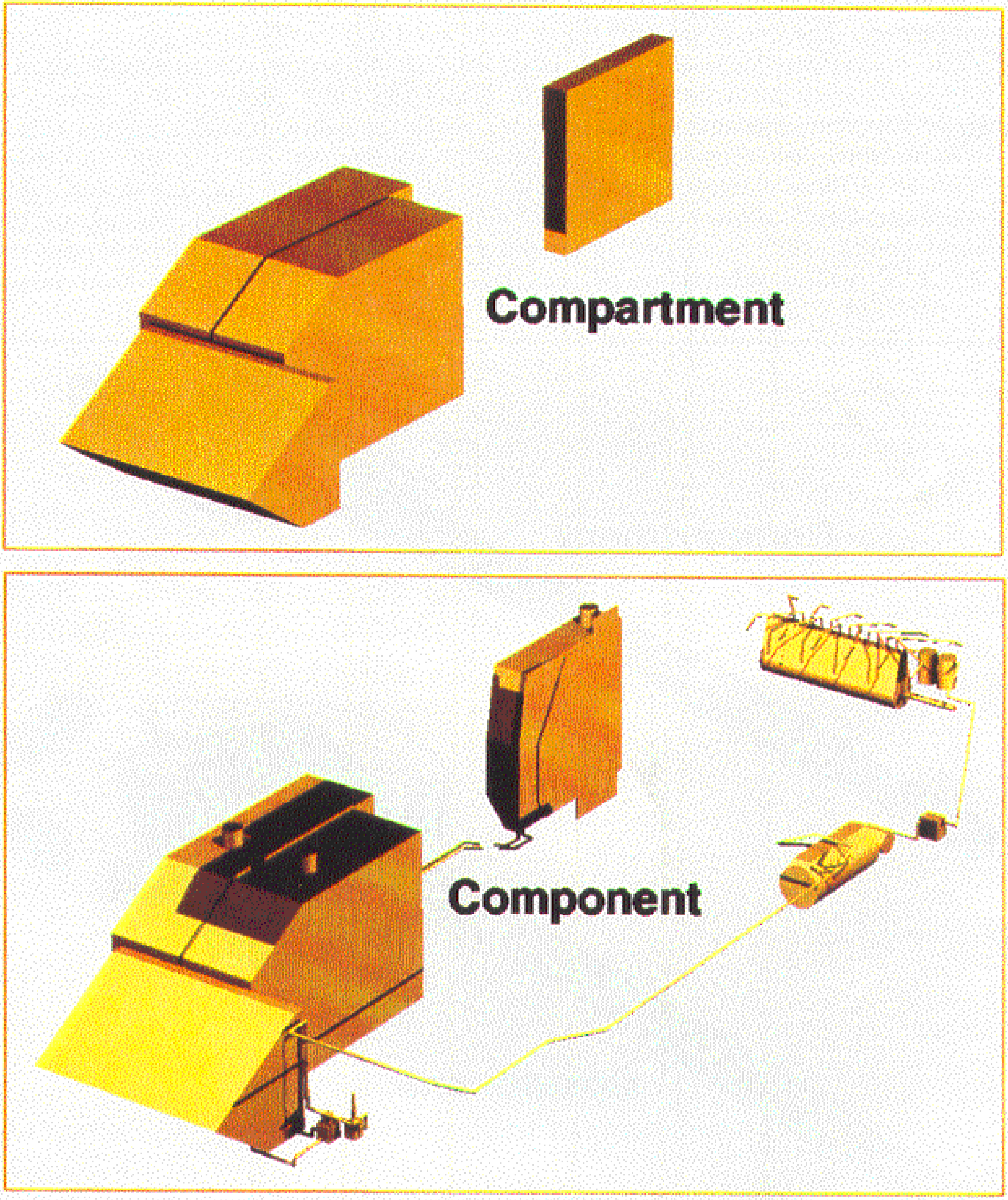


Figure 11. Compartment-Level and Component-Level Fuel System.

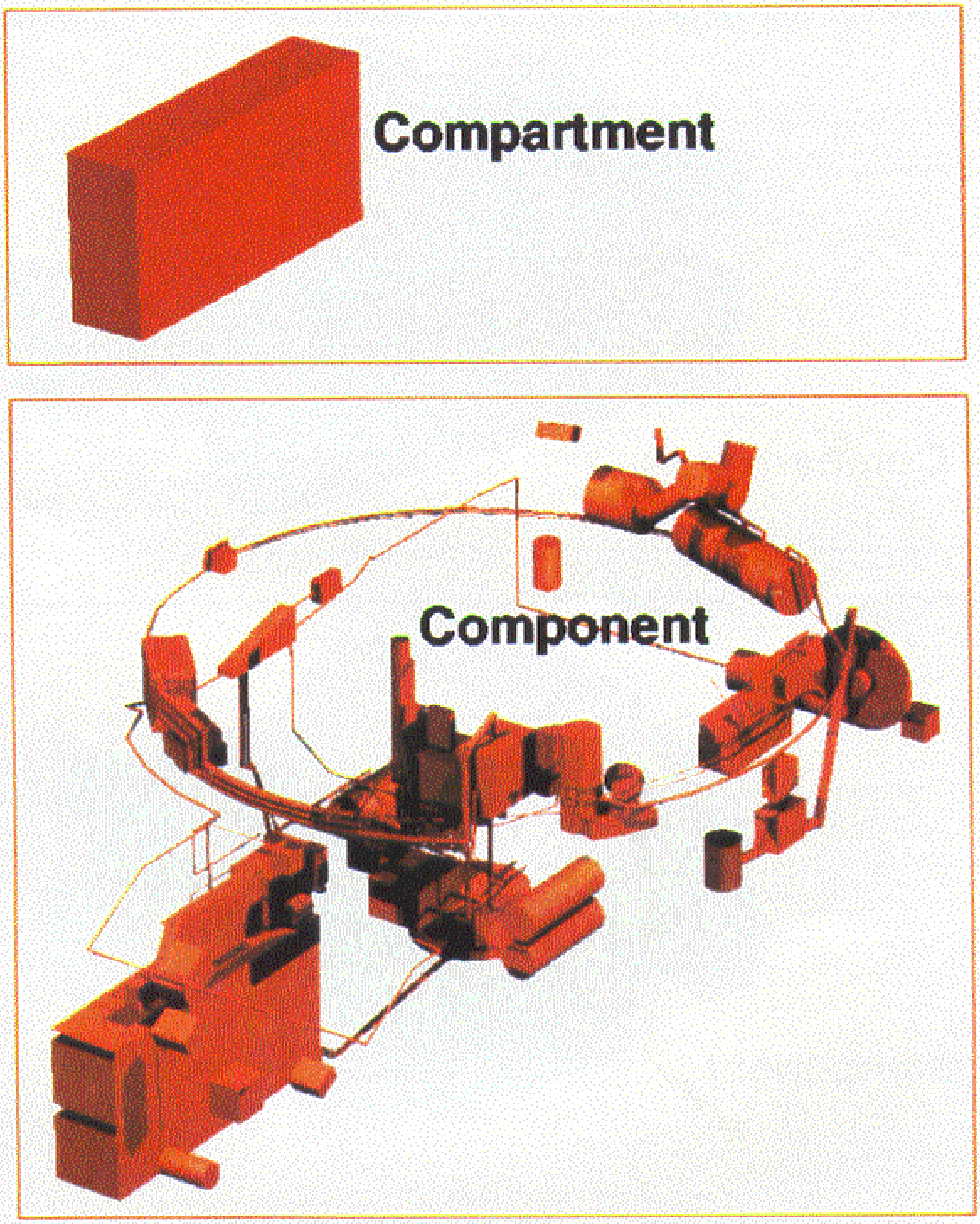


Figure 12. Compartment-Level and Component-Level Electrical System.

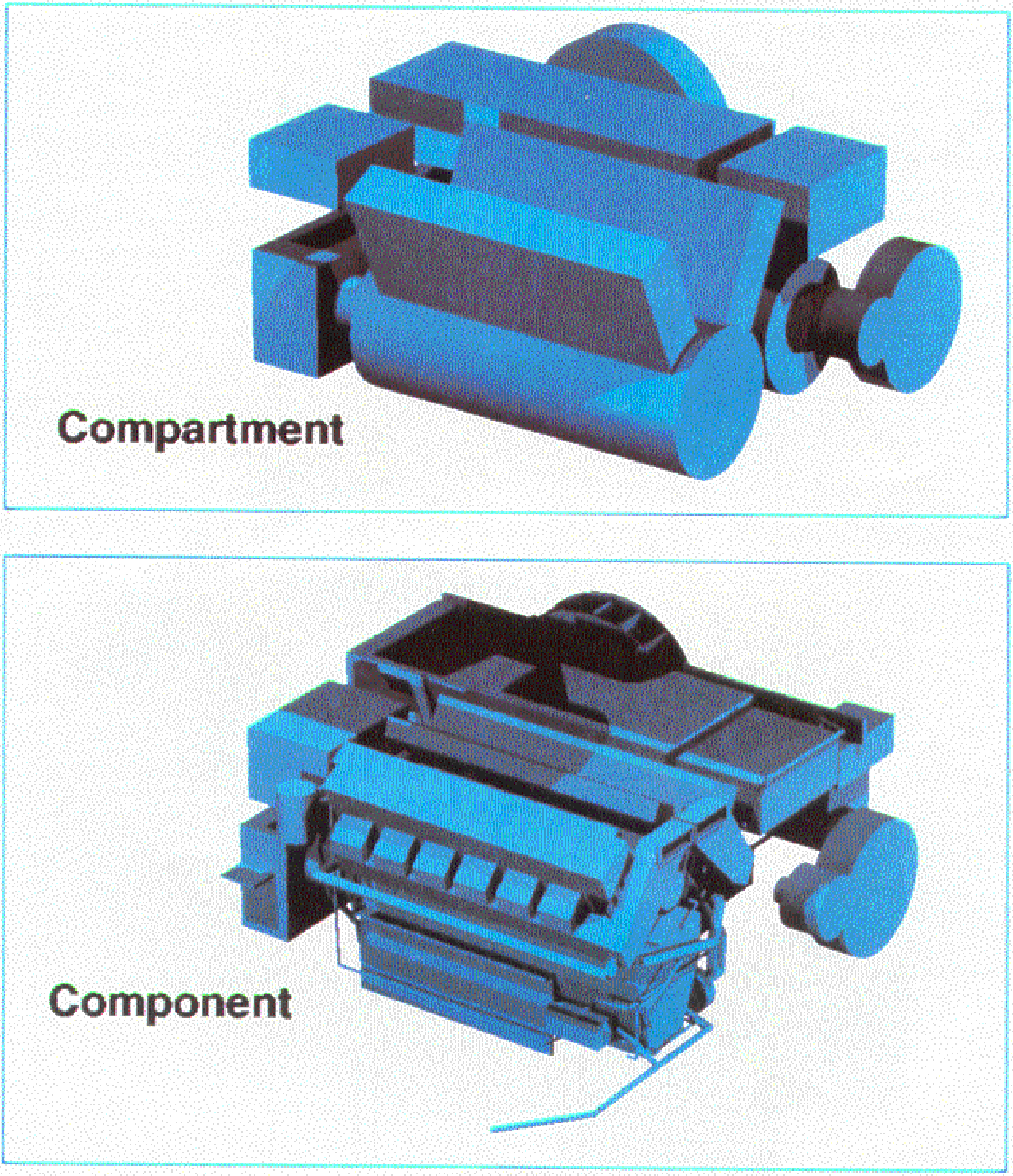


Figure 13. Compartment-Level and Component-Level Power Train.

3.5 SPARC

For many years, spare parts for military systems were stocked according to life expectancies and mean-time-between-failures in a peacetime environment. Little consideration was given to parts likely to be damaged in battle. In the early 1980s, the **SPARC** (**S**ustainability **P**redictions for **A**rmy spare component **R**equirements for **C**ombat) program was started to address this oversight. The SPARC[12] code was developed to quantify spare parts requirements in support of combat damage repair. The SPARC methodology is really an adaptation of the point burst methodology and, therefore, accounts for damage from both the main penetrator and spall debris. The major difference was the introduction of the concept of the *mission-essential component,* a more inclusive classification than the standard V/L critical component. Any component whose loss would require repair or replacement either to prevent damage to other components or to maintain long-term operational readiness and reliability is considered mission essential.

SPARC target description requirements are basically the same as the point burst V/L analysis, except for the concept of mission-essential components. All components that would be considered critical in a point burst analysis are also considered mission essential. However, noncritical components may become mission essential if they must be replaced when damaged to maintain long-term operational status. For example, consider the third roadwheel of a tracked vehicle. This roadwheel is not considered V/L critical since the vehicle is still functional when the roadwheel is damaged. However, this damaged roadwheel could lead to problems with other suspension components such as torsion bars and the track and is, therefore, considered a mission-essential component for a SPARC analysis. All mission-essential components, even redundant components, must be uniquely identified. It is necessary, therefore, to assure that the regions used to model a component are uniquely identified, and any other occurrence of that component must be distinguished from others.

3.6 SAR Signature

This methodology predicts **S**ynthetic **A**perture **R**adar (**SAR**) images by ray-tracing the geometric model. At every intersection with the geometry, the ray is reflected in another direction according to the surface geometry and appropriate physical laws. This process is continued until the ray is reflected back to the sensor or leaves the scene.

The geometry requirements for a SAR analysis are quite different than those discussed up to this point. If the target exterior is completely conducting (i.e., metal), then no internal components are required. However, if portions of the exterior shell (or any exterior component) are comprised of nonconducting material (e.g., glass, plastic, etc.), then appropriate internal components should be modeled. Likewise, hubs and rims should be modeled in detail as rubber is also transparent to radar. Generally though, all the detail is concentrated on the exterior surface. Since surface normals and curvature information are required,

the exterior shell must be as accurate as possible. Curved surfaces must be modeled as such and as faithfully as possible. Thicknesses are unimportant, but if known should be modeled accurately. All exterior accessories should be modeled and in great detail. Components such as headlights, taillights, hinges, handles, braces, supports, large bolt heads, and individual track links should be included in the model. Even rounded corners should be considered for larger components such as external fuel tanks. This detail is required since any condition that might possibly give a SAR return (e.g., a small corner reflector) should be geometrically modeled. **Figures 14** and **15** are exterior views of a SAR-level target description with several areas of detail highlighted.

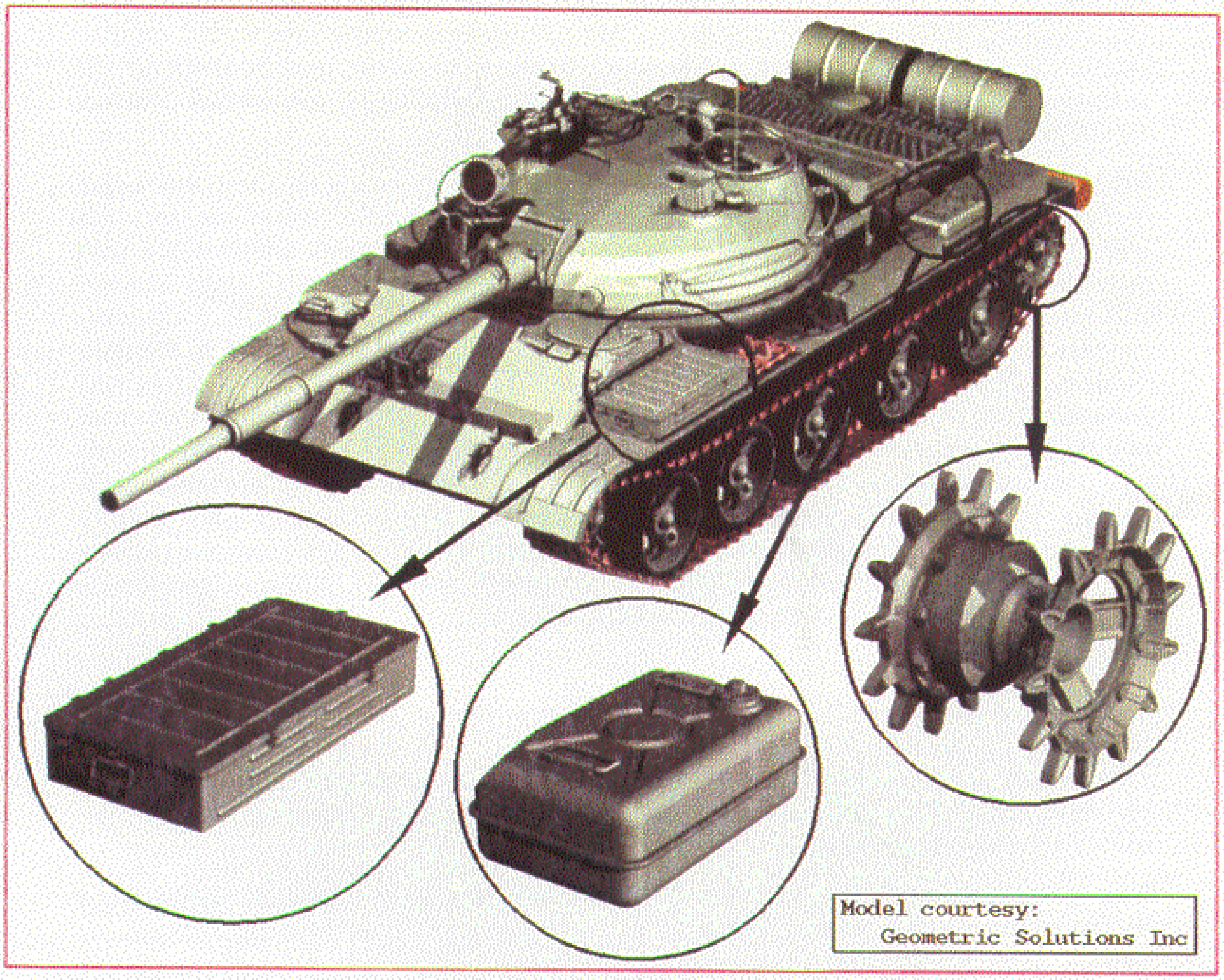


Figure 14. Example of a SAR-Level Target Description.

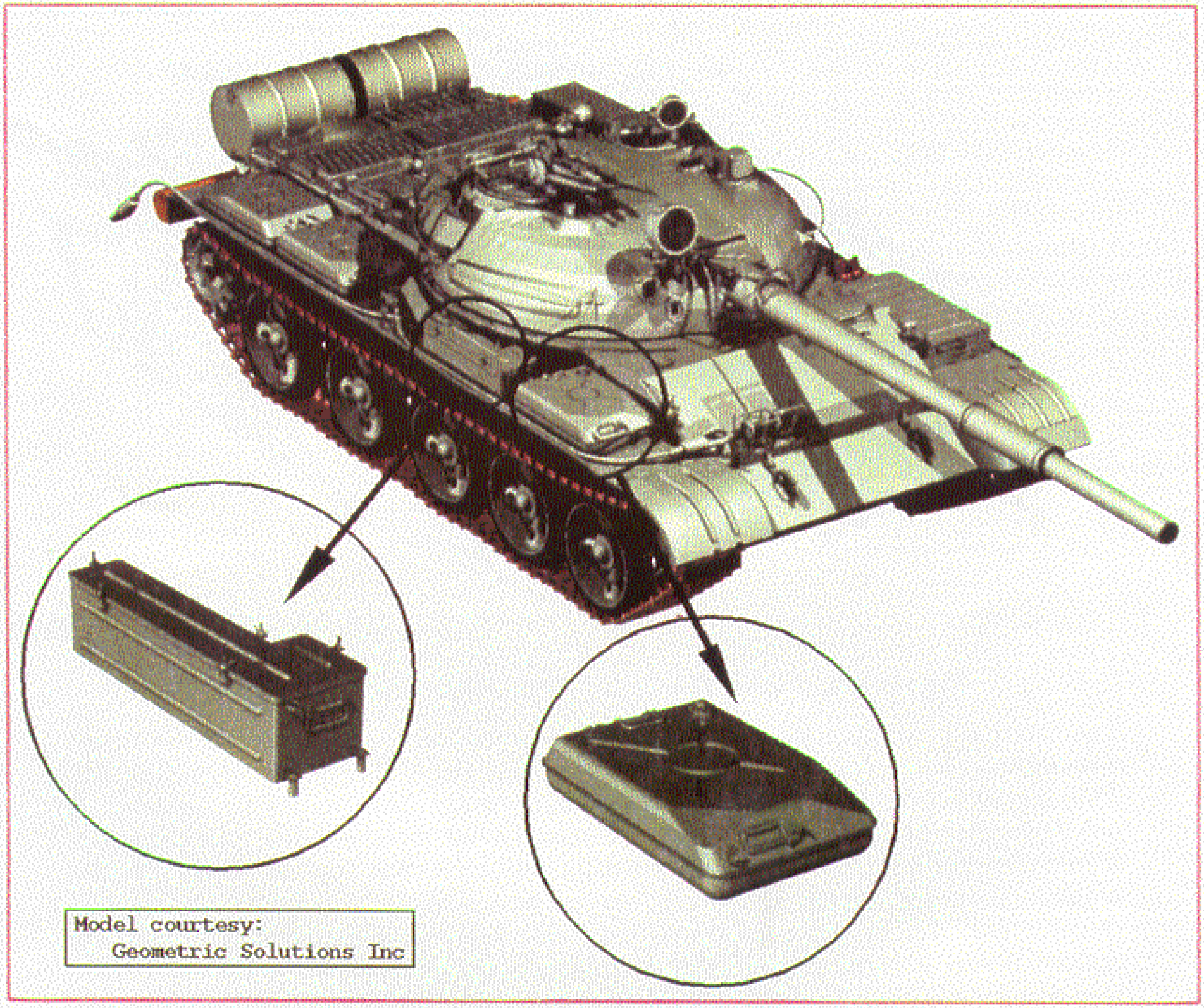


Figure 15. Example of a SAR-Level Target Description.

3.7 IR Signature

The InfraRed (IR) methodology is designed to predict surface temperatures of targets. The Physically Reasonable Infrared Signature Model (**PRISM**)[13] code is one of several such codes in use today. The PRISM code is a lumped parameter finite difference model which requires that geometric regions be represented as nodes. Thus, conversion processes are required to prepare a CSG model for input to this thermal model. The conversion process uses the geometry to create the nodal inputs (see **Figure 16**). Afterwards, the geometry is again referenced to display the resulting thermal predictions. The **F**aceted **R**egion **ED**itor (**FRED**)[14] and the IRPREP[15] are two such codes designed to convert BRL-CAD geometric models for input to the PRISM code.

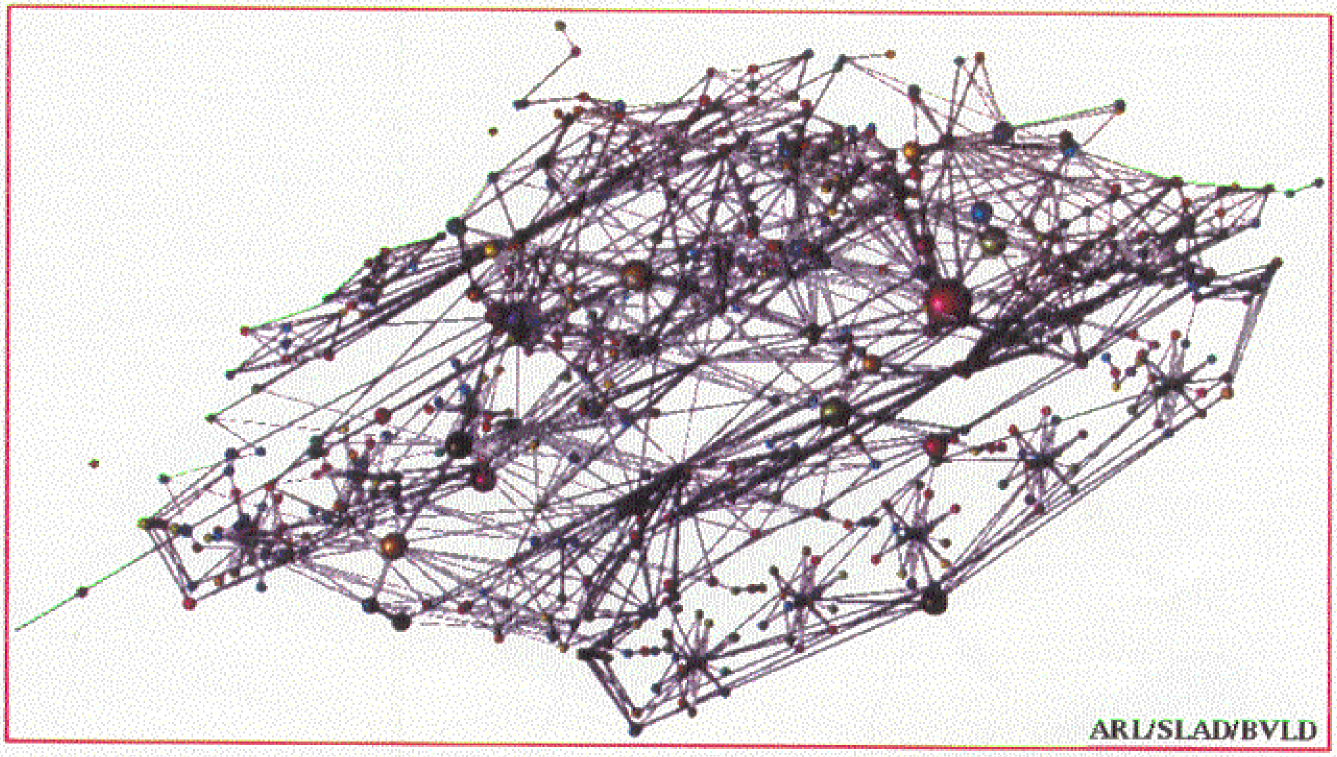


Figure 16. Nodes Converted From BRL-CAD Geometry.

The thermal prediction models do place several unique requirements on the target description. The heat flow analysis requires that the CSG regions be isothermal. This means portions of the exterior shell of a vehicle, that would be modeled as one region for ballistic V/L analyses, may now need to be divided into a number of smaller regions to reduce temperature variance over the regions. PRISM requires that any region have only one surface normal. To accommodate this requirement, during the conversion, the surface normals are averaged over the region; hence, a large region with numerous surface normals should be divided into smaller regions. For example, if the turret of a tank is modeled as one large region, there will be only one surface normal associated with the whole turret (see **Figure 17**). As in the compartment and point burst V/L descriptions, the internal volume must be modeled as air regions. The only interior components required are those comprising the engine and air intake and exhaust ducts. All these requirements are further explained in the IRPREP reference.

4. Managing BRL-CAD Data Files

In the following sections, we will discuss the BRL-CAD data file and suggest an approach to managing it. The data file is designed to allow storage of huge volumes of information. In the 1970s, target descriptions consisting of 1,000 objects were considered high detail, yet today there are descriptions consisting of tens of thousands of objects. Individual components have been treated as a

system themselves and modeled down to the "wire" level (see **Figure 18**). Descriptions of dozens of separate targets have been combined in one file to represent whole military units (see **Figure 19**). All of these feats owe their success to the design and flexibility of the BRL-CAD database. We will look at how the data are stored, the internal file structure, and how data are referenced and organized.

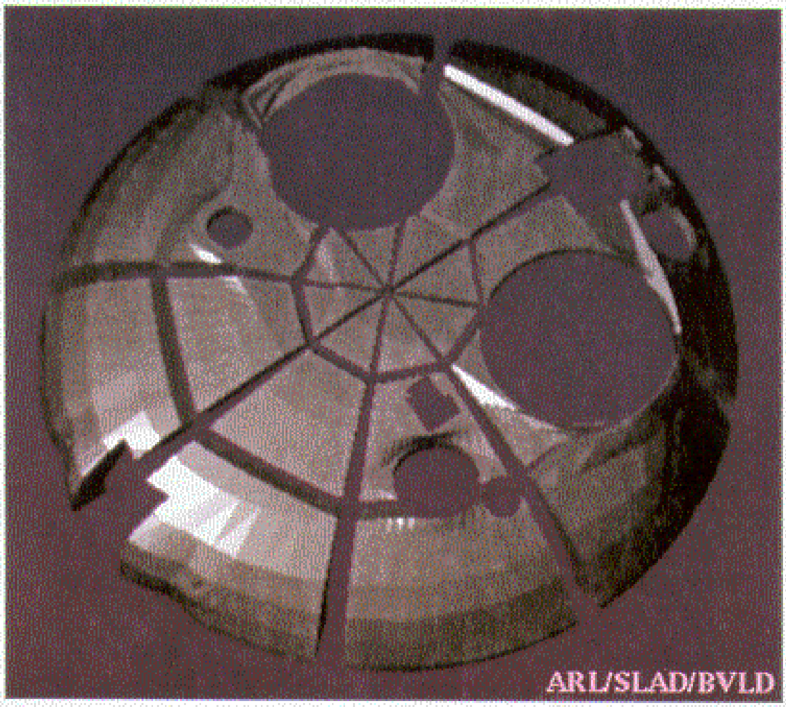


Figure 17. Sliced Turret to Produce Different Normals.

4.1 Data File Structure

The BRL-CAD data file is a binary UNIX file of sequential blocks or records of data. The actual organization of the data in any particular record depends on the type of information stored there. There are only two main types of records, the *solid* record and the *combination* record. The solid record stores all the parameters necessary to define the various primitives. The combination record is used to store all the other nonsolid objects. Its obvious function is to group any number of objects together. The combination record consists of a *header* record followed immediately by a series of *member* records. It is important to note that each member record in a combination contains a transformation matrix. Any editing is stored in these matrices. If the whole combination is edited, then every member matrix is modified to reflect this editing. Any member of a combination may be edited as part of that combination. In this case, only the appropriate member matrix is modified. The important fact to remember is that any editing of combinations is stored in transformation matrices. On the other hand, any editing of solids results in actual changes in the stored parameters.

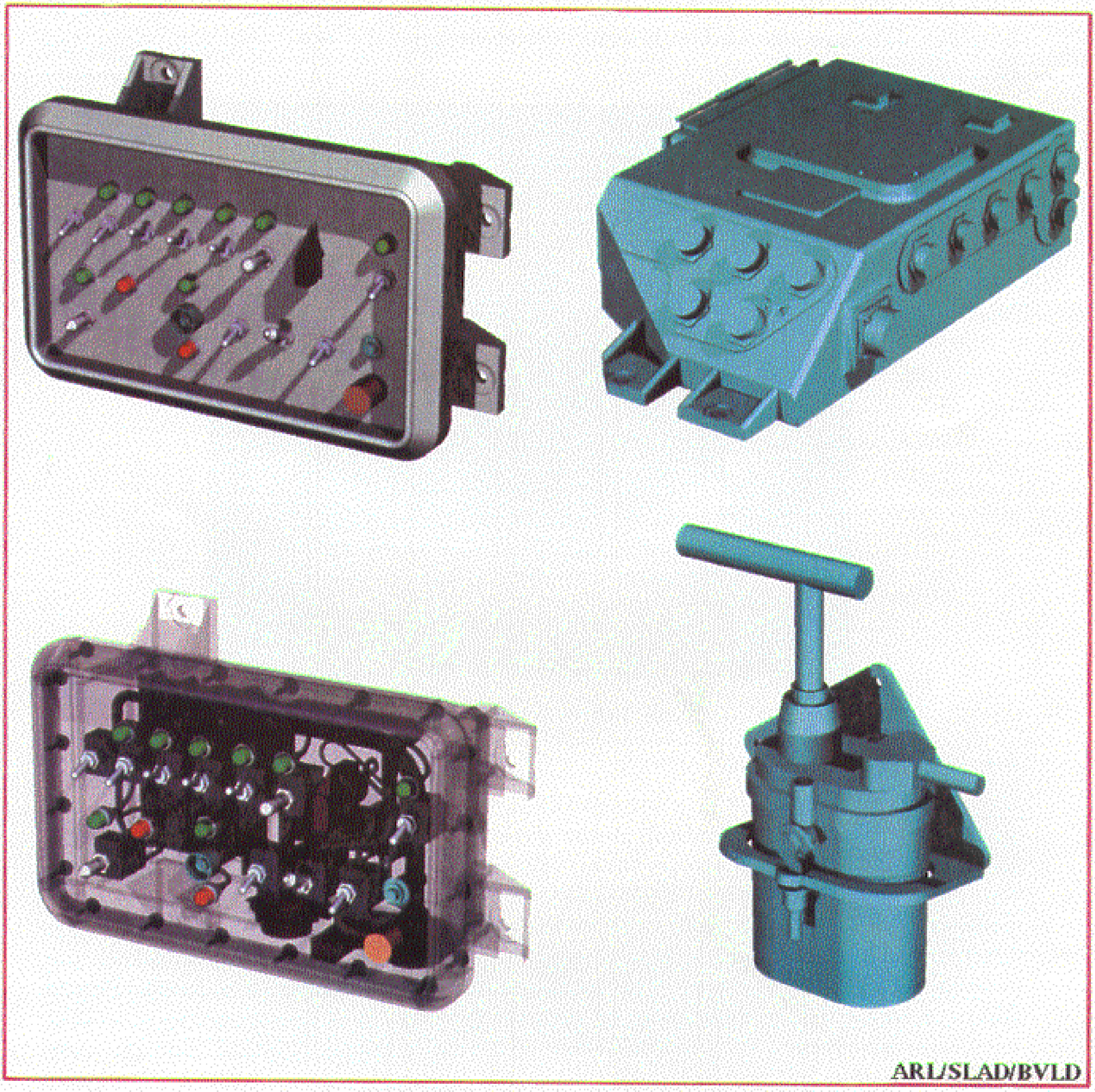


Figure 18. High Detailed Individual Component Modeling.

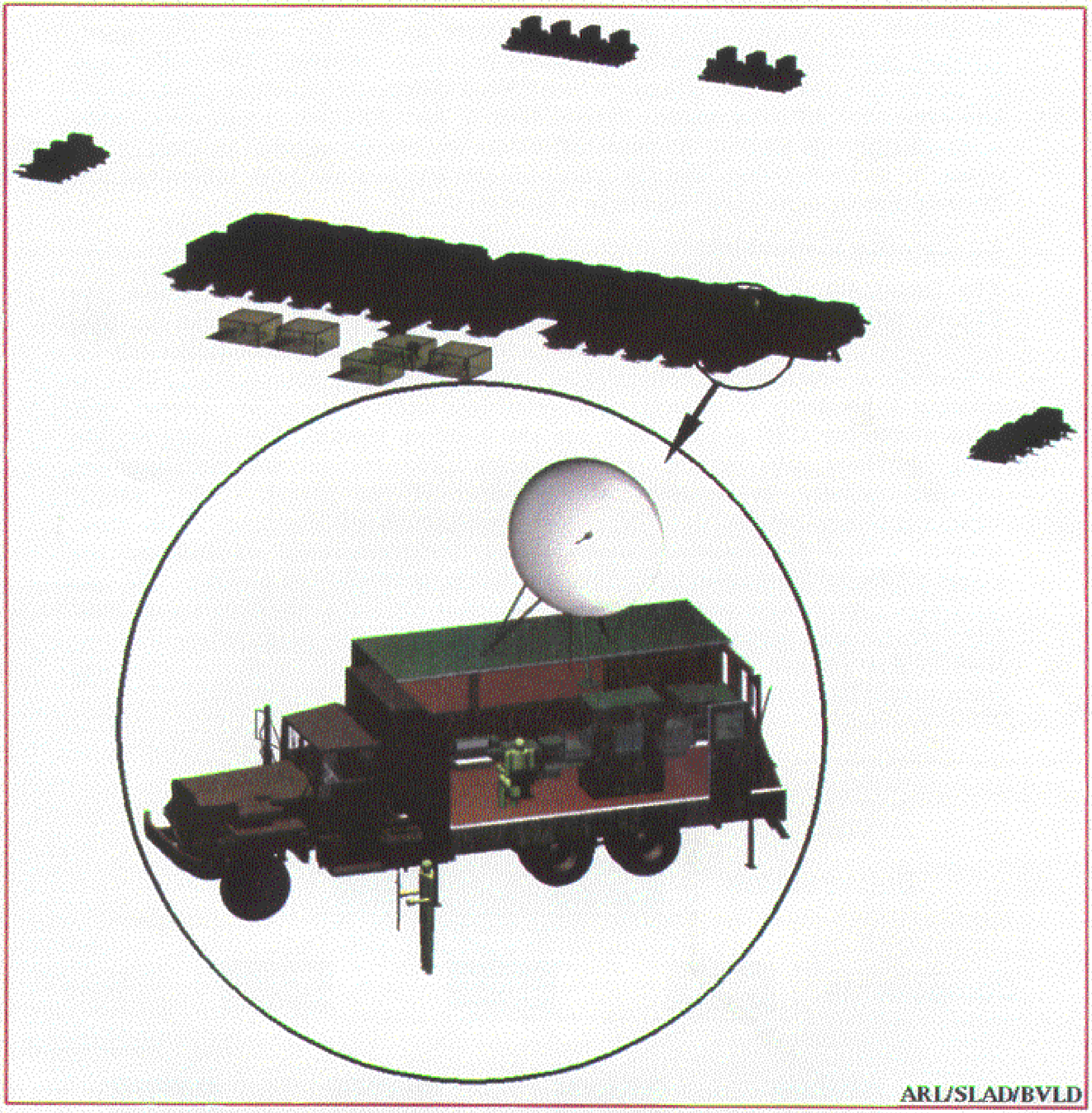


Figure 19. Model of a Corps Command Post.

All objects in the BRL-CAD data file are referenced by a name. This name must be unique and may consist of any characters on the keyboard. One must, however, avoid using any special characters in a name, especially the /, \, *, and !. Upper and lower case letters are considered different characters; thus, *Armor* and *armor* are different names. Names such as *plate#23(t=2.5)* and *wire_1w235* are perfectly legal names. As expected, names are usually selected to identify the object as to its function, and the whole process has become quite individualized. We will discuss more about names in a later section.

4.2 Creating Hierarchies

The BRL-CAD data file is naturally organized in a hierarchical nature (see **Figure 20**). From the discussion earlier about data records, one can see that every object in the data file is either a member of some combination or by definition, a top-level object. Hence, just by creating combinations, one is creating a hierarchy of objects. The primitives (solid records) are created first since under the CSG scheme they are the building blocks. The primitives are then combined into regions (combinations). The regions are next grouped together, usually to represent a component of the target. Next, several components are combined to represent a subsystem of the target. As these natural, logical groupings are accomplished, the hierarchical structure of the target emerges. This grouping process continues until one combination, *the top-level object,* represents the complete target. This hierarchy has been constructed from the bottom, where all the solids were defined, to the peak, where the top-level object reigns. This hierarchy is *evaluated* opposite of the way it was constructed, i.e., from the top, down.

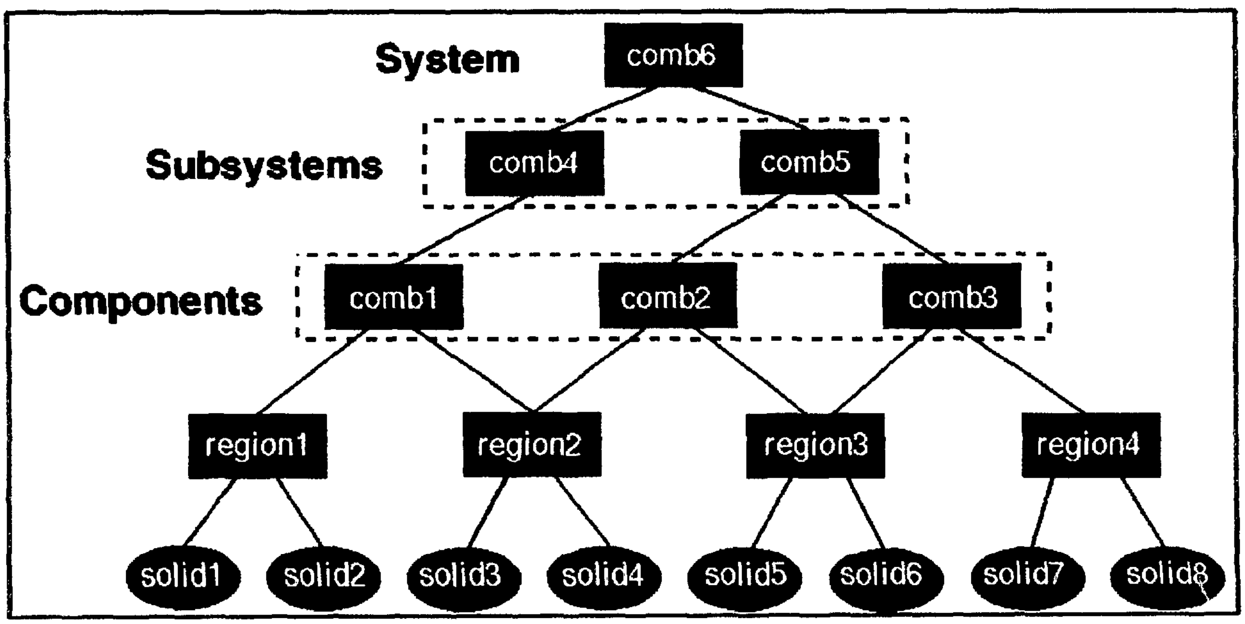


Figure 20. The BRL-CAD Hierarchical Data Structure.

4.3 Some Conventions

As the modeling of a target progresses and the hierarchical structure takes shape, the user has the freedom to select names on a personal preference basis. However, it is beneficial to other users of the data if some conventions or standard practices are observed in the selection of the names. The following scheme is presently in use at the BVLD for the construction of BRL-CAD models of armored vehicles. This scheme can be used as a guide in selecting similar naming conventions for other classes of targets. The naming conventions for armored vehicles are concerned only with the top few levels of the hierarchy. The modeler is free to be creative at the lower levels.

As previously discussed in detail, BRL-CAD target descriptions are utilized in several V/L applications. It is only logical, therefore, that the top-level name[s] should indicate the intended usage. Upon seeing the top-level object name, any user would then know the intended application and, therefore, how the target was modeled. Note that the "tops" command in MGED (the BRL-CAD geometry editing code) will list all top-level objects in a BRL-CAD file. As we have seen, components are modeled differently depending on the intended application, and this difference is often in the amount of detail. The hierarchical nature of the data file allows one to create several versions of a single component while sharing common geometry. Extending this feature allows several versions of the same target to coexist in the database, sharing common elements. With this in mind, each top-level name has two characters assigned which are used to distinguish lower-level names. In the armored vehicle naming scheme, the following top-level names have been selected (the assigned two characters are in parentheses): *nuclear (nu), compartment (ca), component (co), sparc (sp), radar (ra),* and *infrared (ir).* As new applications arise, a similar top-level name and associated two-character designator will be chosen.

At the next level immediately below the top level, which we will call the (-1) level, we have selected three names: *turret.nn, hull.nn,* and *suspension.nn.* The "nn" suffixes represent the two characters assigned to the top-level names. At the next level below each of these names, the (-2) level, we have selected three names for the hull.nn and turret.nn groups. No further names have been selected for the suspension.nn group. For the turret.nn group, the following names have been selected: *tur.ext.nn, tur.int.nn,* and *tur.air.nn.* As no surprise, the following names have been selected for the hull.nn group: *hull.ext.nn, hull.int.nn,* and *hull.air.nn.* These lower-level naming conventions for armored vehicles are summarized in **Table 1.**

TABLE 1. Lower-Level Naming Conventions for Armored Vehicles.

Names	
(-1) Level	(-2) Level
turret.nn	tur.ext.nn tur.int.nn tur.air.nn
hull.nn	hull.ext.nn hull.int.nn hull.air.nn
suspension.nn	-none-

5. Modeling Philosophy

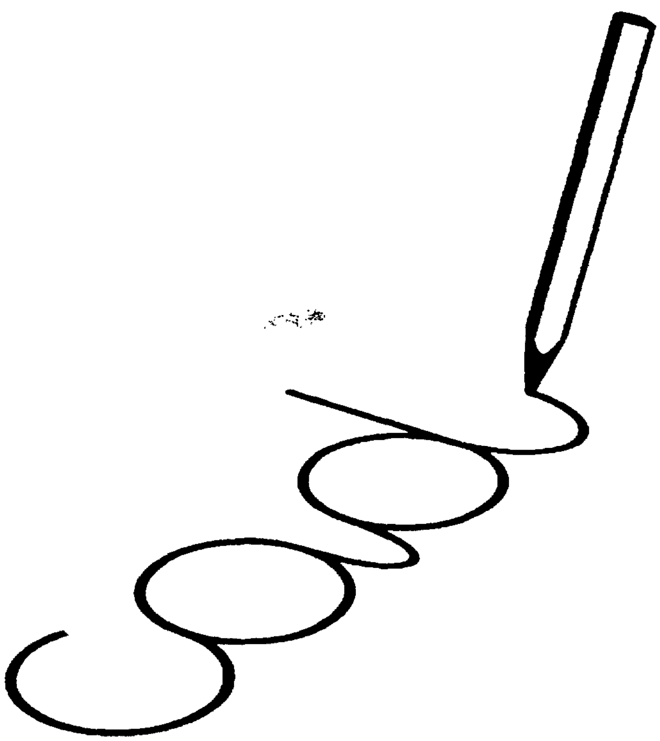
Probably one of the difficult parts of geometric modeling is where and how to begin the process. As with most procedures, the first step should consist of a review, analysis, and planning phase. Hopefully, some of what has been presented up to this point will help in this initial phase. The modeler should think about the task that lies ahead, considering such things as the following: just exactly what is the final expected product; what will the model be used for; how much descriptive information is available, and what form is it in; what, if anything, has been done in the past; and can existing ("library") components be used. Next, one should devise a general plan on how to accomplish the actual construction of the model, including rough time estimates for each phase. This general plan should include all the major subsystems of the target that must be modeled. For most military targets, the tersest general plan would consist of the following: (1) model the exterior shell, (2) model the internal air, and (3) model all the remaining components. Of course we are being facetious about step (3), but steps (1) and (2) of this general plan are genuine. The goal is to get a "correct" exterior shell (with internal air if necessary) before any components are added. If a tank were being modeled, the first steps might become as follows: model the hull shell, model the hull air, model the turret shell, and model the turret air.

Finally, since much of the modeling effort goes into step (3) (model all remaining components), we will discuss how to model components. This discussion will be more "cookbook" oriented, but we still will not go into the details. Other publications[16] have discussed geometric modeling with BRL-CAD in detail. As always, initially, time should be spent analyzing and planning. First analyze the component to be modeled and decide on the detail required, formulating exactly how to represent the component, including what solids to use and how to combine them into regions. Then create the solids, so they have the desired shape, size, and orientation. To take advantage of any symmetry, create the solids at the origin. Next combine the solids into the regions, then group these regions into a combination representing the completed component. At this point check for and

fix any interferences (regions occupying the same volume) within the component and create pictures for visual verification. Note that both of these actions are performed using ray-tracing. The model of the component is now completed, so it's time to move it to its location within the target. This task is accomplished by editing the combination (translate, scale, and/or rotate). Recall, this editing is stored in the matrices of the member records, so the components primitives (solid records) are still at the origin. It is recommended to "push" (an MGED command) this editing down to the solid records at this time. Next check for and fix any interferences between this component at its new location and the rest of the description. This process is repeated for every component that is to be modeled.

6. Summary

In this paper we have presented a general, overview type of approach to geometric modeling with BRL-CAD. We outlined the important link between the intended application and the overall requirements of the geometric model. We looked at an approach to effective BRL-CAD database management, based on the design of the database structure itself. We also presented some standard naming conventions that have proven effective for armored systems. Finally, we discussed the philosophy of geometric modeling and presented a general plan to accomplish any modeling project.



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